

AN INTRODUCTION TO PUMP SYSTEMS

1.0 HYDROSTATIC PRESSURE AND FLUID COLUMN HEIGHT

Our starting point will be pressure and how it is developed within a pumping system. It is easy to build pressure within a solid, a fluid however requires containment walls. A fluid can only be pressurized if it is in a container. Sometimes the container is very big like an ocean. This does not mean that the container has to be closed. Even if the container has an outlet, it is still possible to build pressure. An experiment with a common syringe will demonstrate this fact. With the syringe full of water, it is quite easy to generate significant pressure within the fluid (this is evidenced by the amount of force applied to the plunger) even while fluid squirts from the tip.

Hydrostatic pressure is the pressure associated with a motionless body of water. Pressure within the body of water varies and is directly proportional to the vertical position with respect to the free surface. Divers are well aware of this fact since each foot of vertical descent increases pressure on the eardrums.

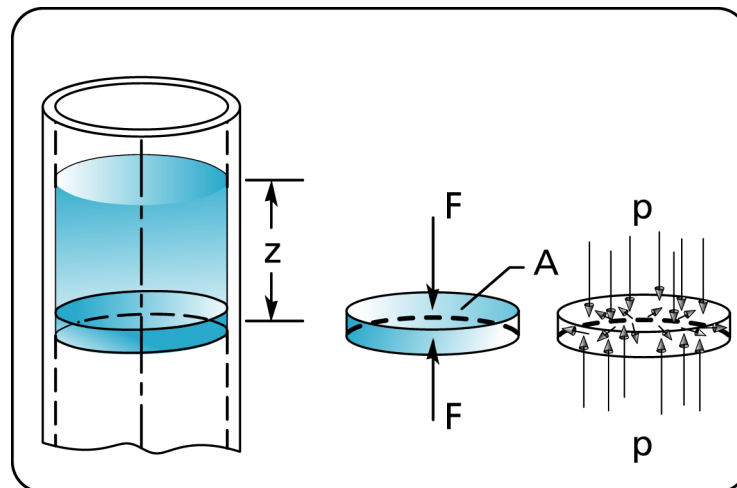


Figure 1-1 Pressure vs. hydrostatic head.

Fluid weight is the cause of hydrostatic pressure. In Figure 1-1, a thin slice of fluid is isolated so that the forces surrounding it can be visualized. If we make the slice very thin, the pressure at the top and bottom of the slice will be the same. The slice is compressed top and bottom by force vectors opposing each other. The fluid in the slice also exerts pressure in the horizontal direction against the pipe walls. These forces are balanced by stress within the pipe wall. The pressure at the bottom of the slice will be equal to the weight of fluid above it divided by the area.

The weight of a fluid column of height (z) is:

$$F = \rho g V = \gamma V = \gamma z A \text{ since } V = z A$$

The pressure (p) is equal to the fluid weight (F) divided by the cross-sectional area (A) at the point where the pressure is calculated :

$$p = \frac{F}{A} = \frac{\gamma z A}{A} = \gamma z \quad [1-1]$$

where F : force due to fluid weight

V : volume

g : acceleration due to gravity (32.17 ft/s²)

ρ : fluid density in pound mass per unit volume

γ : fluid density in pound force per unit volume

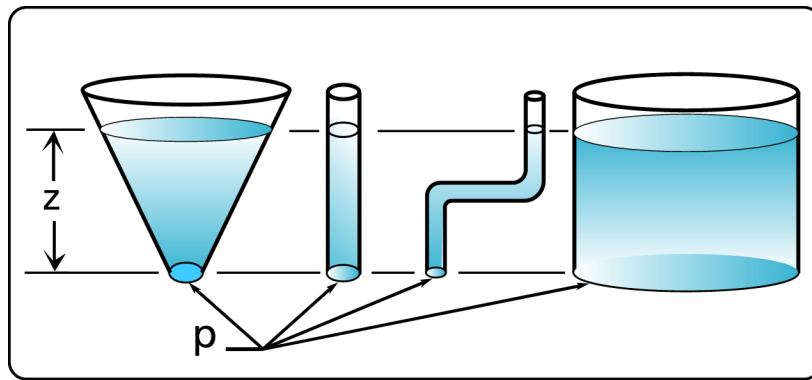


Figure 1-2 Fluid container shapes vs. pressure head.

Note that the relationship between pressure (p) and fluid column height (z) is independent of the total volume in the container. The pressure generated by the weight of water at the deep end of a pool (i.e. 10 feet down) is the same as ten feet below the surface of a lake.

1.1 THE THREE FORMS OF ENERGY

There are three forms of energy that are related and always occur together in a fluid system. They are potential, kinetic and pressure energies. This section briefly provides the definition for each to give the reader some familiarity with the terms. If we divide energy by the weight of the fluid element we obtain specific energy or head.

POTENTIAL SPECIFIC ENERGY

$$\text{Potential specific energy} = z$$

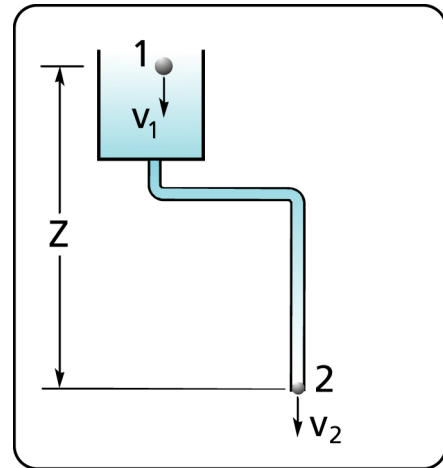


Figure 1-3 Potential specific energy provided by the difference in elevation of fluid particles.

KINETIC SPECIFIC ENERGY

$$\text{Kinetic specific energy} = \frac{v^2}{2g}$$

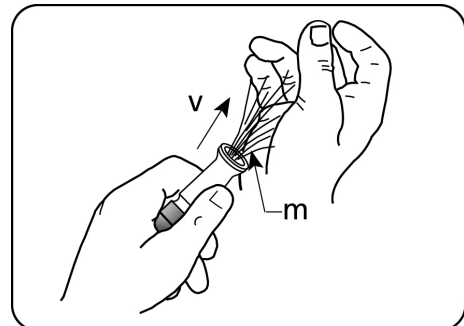


Figure 1-4 Kinetic specific energy provided by moving fluid particles.

PRESSURE SPECIFIC ENERGY

$$\text{Pressure specific energy} = \frac{p}{\gamma}$$

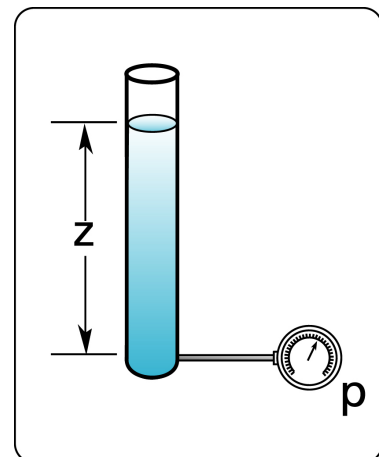


Figure 1-5 Pressure specific energy provided by the weight of a fluid column.

1.2 THE RELATIONSHIP BETWEEN ELEVATION, PRESSURE AND VELOCITY IN A FLUID

There is a relationship between the energies associated with elevation, pressure and velocity of fluid particles. The energy terms are: the elevation energy (z), the pressure energy (p/γ), and the velocity energy (v^2/g). The sum of these 3 types of energy must be constant, since energy cannot be lost. Stated in another way: the energy at point 1 must be equal to the energy at point 2 (see Figure 1-6).

The sum of the three forms of energy must be constant:

$$z + \frac{p}{\gamma} + \frac{v^2}{2g} = \bar{E} = \text{CONSTANT}$$

Or if we wish to describe the relationship between the energy levels of fluid particles in different locations of the system such as point 1 and 2 in Figure 1-6 then:

$$z_1 + \frac{p_1}{\gamma} + \frac{v_1^2}{2g} = z_2 + \frac{p_2}{\gamma} + \frac{v_2^2}{2g}$$

Relationship between pressure, elevation and velocity

A variation in one or two of these terms implies a variation in the third. The total energy at point 1 in a fluid system must be equal to the total energy at point 2 (see Figure 1-6). For example, if we were to increase the velocity at point 1 by reducing the section, keeping all the other terms the same, the pressure p_1 will decrease.

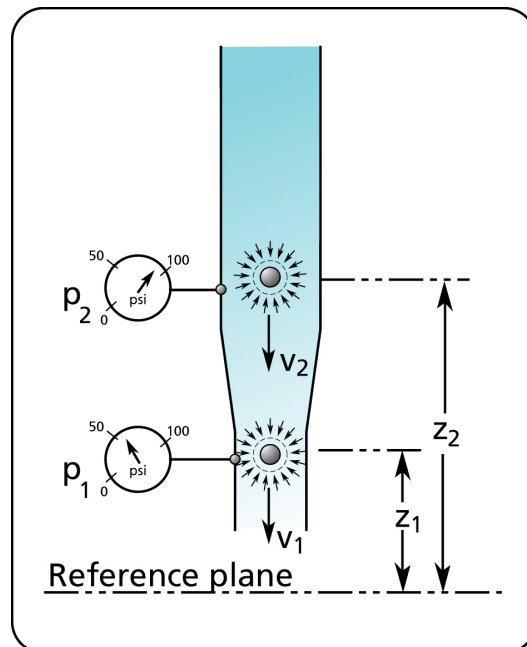


Figure 1-6 The relationship between pressure, elevation and velocity.

Relationship between pressure and elevation

There are many areas in a system where the velocity is constant. In that case, it is only pressure and elevation that are related. In particular, if the velocity is zero as in a static system, we have the relationship between pressure and fluid column height previously mentioned.

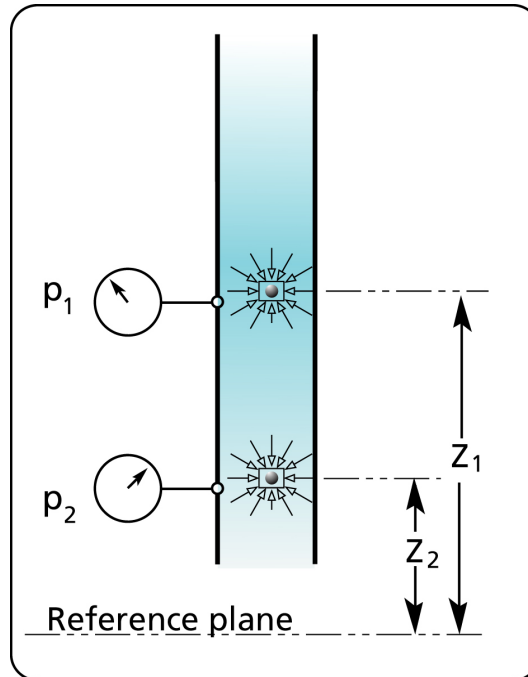


Figure 1-7 The relationship between pressure and elevation.

The following equation gives the relationship between elevation and pressure when the velocity is constant.

$$z_1 + \frac{p_1}{\gamma} = z_2 + \frac{p_2}{\gamma}$$

Figure 1-8 shows a real system with a pressure gauge at the low part of the system (near the pump) and one in the upper part (near the discharge tank). The pressure p_1 will be greater than p_2 due to the elevation difference.

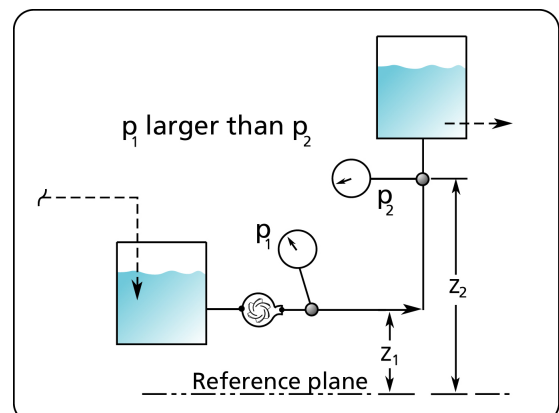


Figure 1-8 Pressure variation due to elevation in a real system.

Relationship between pressure and velocity

If the elevation is constant, then there is a relationship between pressure and velocity. It is this relationship that helps us calculate the flow rate in a venturi tube. In Figure 1-9, the pressure p_2 will be lower than p_1 due to the increase in velocity at point 2.

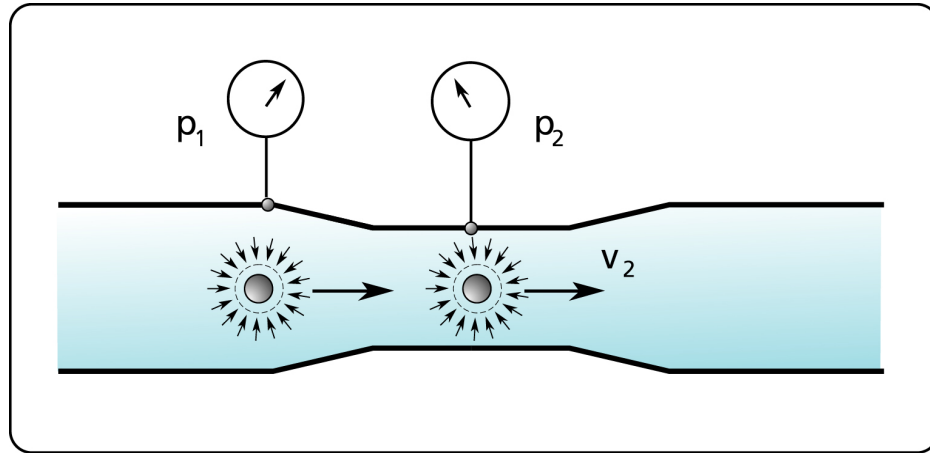


Figure 1-9 The relationship between pressure and velocity.

The following equation gives the relationship between pressure and velocity when the elevation is constant.

$$\frac{p_1}{\gamma} + \frac{v_1^2}{2g} = \frac{p_2}{\gamma} + \frac{v_2^2}{2g}$$

A venturi tube is used to measure flow rate. The flow rate (q) is proportional to the difference in pressure at points 1 and 2 (see Figure 1-9).

$$q = K \sqrt{\frac{p_2 - p_1}{\gamma}}$$

The 3 forms of energy (elevation, pressure and velocity) are always present in a fluid system. Using a simple container (see Figure 1-10), these types of energy can be clearly demonstrated.

1. **Potential energy.** The fluid particles at elevation z vs. those at the bottom have potential energy. We know this type of energy is present because we must have spent energy moving the fluid particles up to that level.
2. **Pressure energy.** The weight of the fluid column produces pressure p at the bottom of the tank. The pressure energy is transformed to kinetic energy when we open the valve at the bottom of the tank.
3. **Kinetic energy.** If fluid is allowed to exit the container at the bottom of the tank, it will exit the tank with a velocity v . Pressure energy has been converted to kinetic energy.

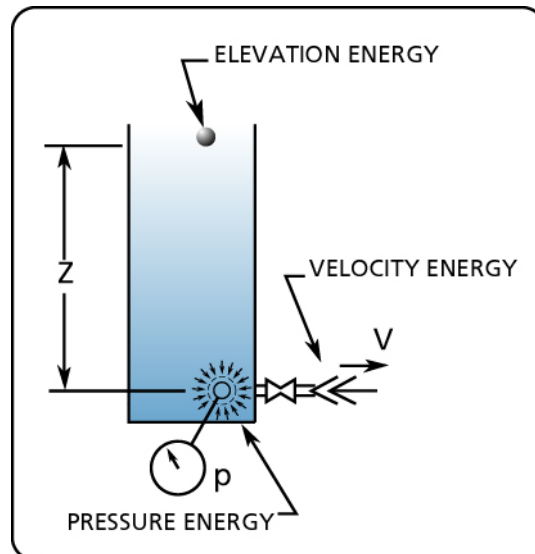


Figure 1-10 The 3 forms of energy in a fluid system, potential, kinetic and pressure.

1.3 THE DIFFERENCE BETWEEN PRESSURE AND HEAD

In a moving fluid, the velocity of the particles must be considered. The principle of conservation of energy states that the energy of a fluid particle as it travels through a system must be constant. This can be expressed as:

$$mgz + mg \frac{p}{\gamma} + \frac{1}{2}mv^2 = E = \text{CONSTANT} \quad [1-2]$$

where (E) is the total energy of fluid particles with mass (m) and velocity (v). The total energy consists of the potential energy (mgz), the pressure energy ($mg p/\gamma$), and the kinetic energy ($m v^2/2g$). By dividing all the terms in the above equation by (mg), we obtain equation [1-3] which is known as Bernoulli's equation. E now becomes the specific energy of the fluid particle or the energy per unit weight \bar{E} . All the terms on the left-hand

side of Bernoulli's equation are known as **head**. Bernoulli's equation expresses the relationship between the elevation head (z), the pressure head (p/γ), and the velocity head ($v^2/2g$).

Bernoulli's equation:

$$z + \frac{p}{\gamma} + \frac{v^2}{2g} = \bar{E} = \text{CONSTANT} \quad [1-3]$$

Bernoulli's equation will be expanded later to include the pump Total Head and the friction losses. It is important at this point to make a clear distinction between pressure and head. Head is a generic term for a type of specific energy (i.e. elevation, pressure or velocity head). When we need to calculate pressure at a specific point in a system, we will refer to it as **pressure head**. Pressure head can be converted to pressure by equation [1-1].

Pressure can be measured anywhere in the system quite easily and can provide valuable information. However, since it is not an energy term and cannot be used for calculations involving head, especially Total head. The pressure measurement must be converted to pressure head (see equation [1-5]) to be useful in these calculations.

1.4 FLUID SYSTEMS

The pump is the heart of a fluid system. It is impossible (or at the very least impractical) to move fluid from one place to another without the energy provided by a pump. Figure 1-11 shows a simple but typical system. All the fluid in the suction tank will eventually be transferred to the discharge tank. The purpose of the system is to displace fluid and sometimes to alter it by filtering, heating or other with the appropriate equipment. The box with the term EQ symbolizes equipment such as: control valves, filters, etc. Any device (or equipment) introduced into the line will have the effect of reducing the pressure head in the line. This requires more head, or energy, from the pump.

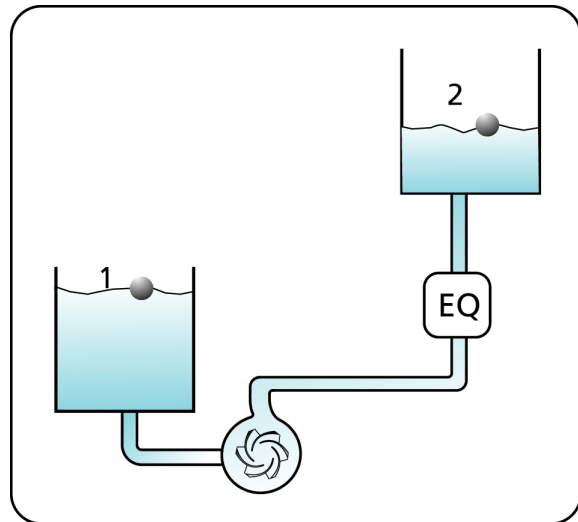


Figure 1-11 A typical pumping system.

How is a system designed?

- A. The flow rate is determined based on the process and production requirements.
- B. The location and size of the suction and discharge tanks is established.
- C. The location, capacity and size of the equipment to be installed in the line is determined.
- D. The pump location is fixed.
- E. The line sizes are determined and the auxiliary equipment such as manual valves are sized and located.
- F. The Total Head of the pump is determined as well as the size, model, type, and power requirement.

Where does a system begin and end?

We can imagine a boundary (also called control volume) which envelops and determines the extent of a system. A complete system contains fluid that is continuous from inlet to outlet. There can be no gaps or empty spaces between parts of the fluid. In Figure 1-11, the system inlet is at point 1 and the outlet is at point 2. Point 1 is located on the liquid surface of the suction tank. Normally there would be a pipe inserted into the suction tank providing fluid to maintain the elevation of point 1. This fill pipe is not considered part of the system. The outlet of the system, or point 2, is located on the liquid surface of the discharge tank. Again, there is normally a pipe, which controls the level of point 2. This discharge pipe is not part of the system. The reasons for this will be carefully explained when we review control volumes in section 2.7.

1.5 THE DRIVING FORCE OF THE FLUID SYSTEM

The pump supplies the energy to move the fluid through a system at a certain flow rate. The energy is transferred to the fluid by a rotating a disk with curved vanes called an impeller (see Figure 1-12). This movement drives the liquid in a circular path and imparts centrifugal force to it. The pump pushes and pressurizes the fluid up against the casing (or volute). This ability of the pump to pressurize fluids at a certain flow rate provides us with the means to design systems that will meet the process goals (for example, flow and pressure at the desired locations). The Total Head is the difference in head between the inlet and outlet of the pump that produces the flow rate required of the system.

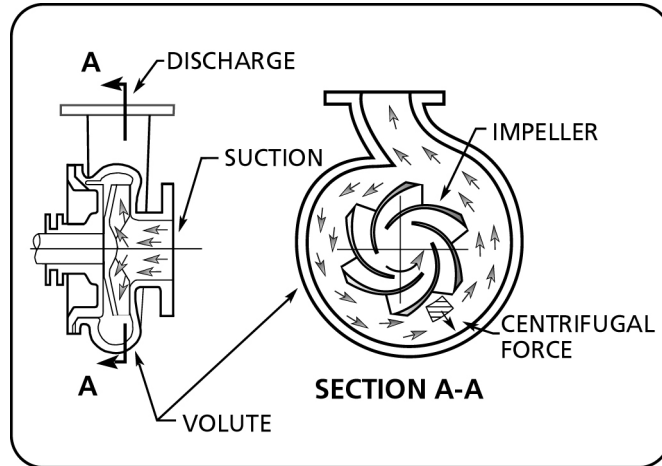


Figure 1-12 Principal components of a centrifugal pump.

The Total Head of the pump provides the energy necessary to overcome the friction loss due to the movement of the fluid through pipes and equipment. It also provides the energy to compensate for the difference in height, velocity and pressure between the inlet and the outlet.

1.6 THE COMPONENTS OF TOTAL HEAD

Friction

Fluids in movement generate friction. There is a difference in pressure ($p_{F1} - p_{F2}$) required to move a fluid element A (see Figure 1-13) towards the outlet. This difference in pressure is known as the friction pressure loss (Δp) (see Figure 1-13). When this term is converted to head, it is then known as friction head loss. Reference tables and charts for friction head loss are widely available (see reference 1 and 8). Viscosity is an important factor and higher viscosity fluids generate higher friction. More about viscosity in chapter 3.

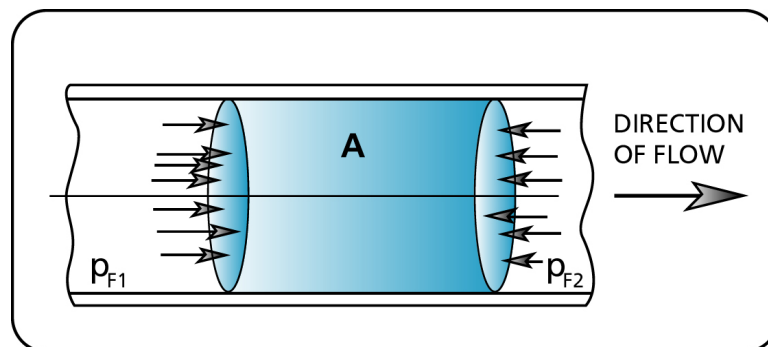


Figure 1-13 The difference in pressure due to fluid friction.

Equipment

Any equipment in the line will create a reduction in pressure head. A filter is a common example of a device producing a pressure drop (see Figure 1-14). Other examples are control valves, heat exchangers, etc. Equipment introduced into an existing system will reduce the flow rate unless the pump is modified to provide more energy (for example by installing a bigger impeller).

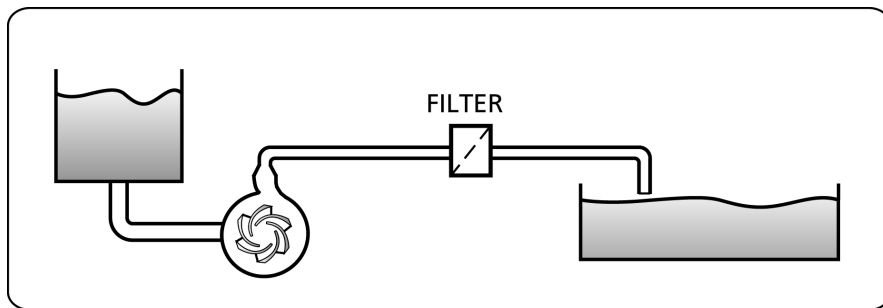


Figure 1-14 The effect of equipment in a system.

Velocity

The kinetic energy of the fluid increases when it leaves the system at a higher velocity than when it enters and this requires extra energy. The energy required for the velocity increase is typically small and is often neglected. However, certain systems are specifically designed to produce high output velocity. This is done by using nozzles (see Figure 1-15 C) and therefore require a substantial amount of energy that the pump must supply. Figure 1-15 illustrates three systems with progressively higher output velocities.

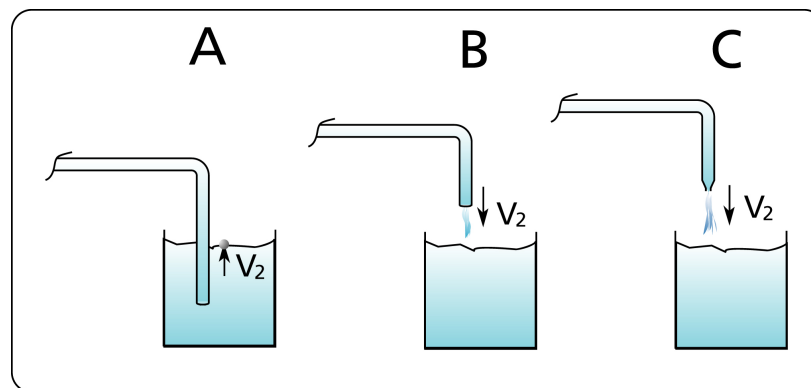


Figure 1-15 Various systems with varying output velocities.

CASE A. DISCHARGE PIPE END SUBMERGED. The output velocity v_2 is small and the velocity head negligible.

CASE B. DISCHARGE PIPE END NOT SUBMERGED. The output velocity v_2 is small and the velocity head is non-negligible.

CASE C. NOZZLES ARE INSTALLED ON THE DISCHARGE PIPE END. The output velocity v_2 is high and the velocity head is high.

Elevation

It takes energy to pump fluids from a lower level to a higher one. There is often a significant difference in elevation between the inlet of a system (point 1), and the outlet (point 2, see Figure 1-16). Typically, the elevation difference within a system is the largest contributor to the Total Head of the pump.

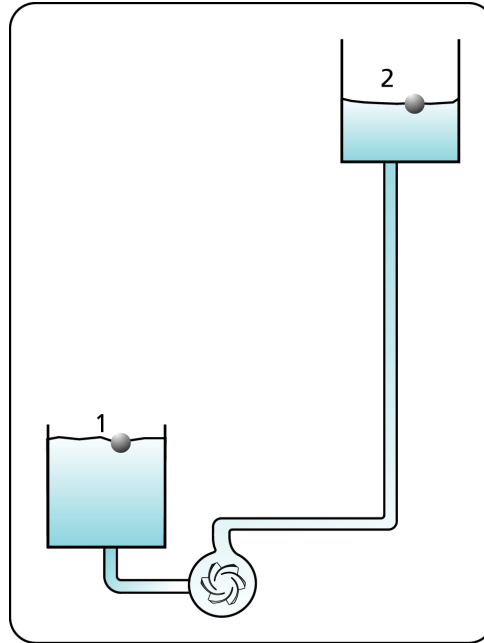


Figure 1-16 The difference in elevation between suction and discharge tank.

Pressurized Tanks

The discharge and suction tank may be positively or negatively pressurized (with respect to the local atmospheric pressure). If the discharge tank is positively pressurized then the pump must provide additional energy to overcome this additional pressure. When the discharge tank is negatively pressurized, there is less resistance to the fluid entering the discharge tank and this reduces the energy required of the pump. The effect on the pump is exactly opposite when the suction tank is positively or negatively pressurized.

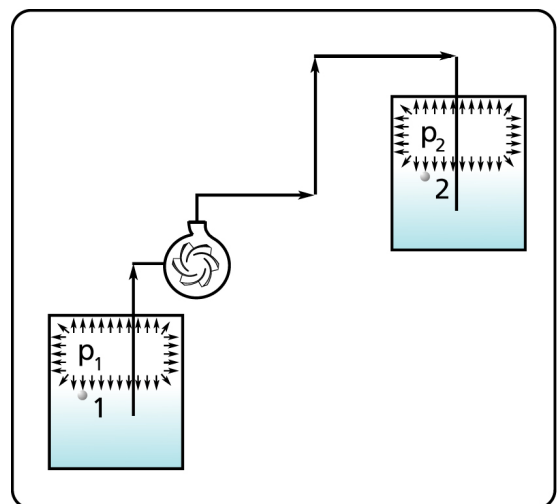


Figure 1-17 Pressurized suction and discharge tanks.

In many applications the tanks are not pressurized and the level of pressure in these tanks is zero or the same as the local atmospheric pressure. However, there is a misuse of terminology that tends to muddy the waters occasionally. Have you ever heard someone say: “Boy, that water is really coming out, there must be a lot of pressure at the end of that hose”. In reality, there is no pressure at the outlet of the hose since the fluid comes out into the atmosphere. What feels like pressure, is the mass of water particles hitting at high velocity. The kinetic energy is converted to pressure energy, which produces a force on the hand. The pressure is zero but the water jet has a significant amount of kinetic energy.

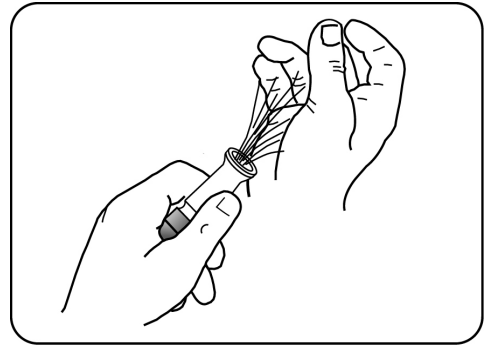


Figure 1-18 Ouch.

1.7 NEGATIVE (RELATIVE) PRESSURE

Figure 1-19 illustrates how easy it is to produce negative relative pressure. The fluid is stationary and the elevation of point 1 is identical to that of points 3, 6 and 9. The pressure at point 2 is higher than the pressure at point 1 due to the depth of point 2 and the pressure caused by the fluid at that depth. The pressure at point 2 is positive and decreases to zero as we reach the level of point 3 (same level as point 1) inside the tube. From 3 to 4, the pressure decreases and becomes negative. The pressure at point 5 is the same as at point 4 since we are on the same level. Pressure then increases from negative to zero at point 6 (same level as point 1). From point 6 to 7 there is a further increase, the pressure remains constant from 7 to 8. The pressure decreases to zero from point 8 to 9 since point 9 is at the same level as point 1.

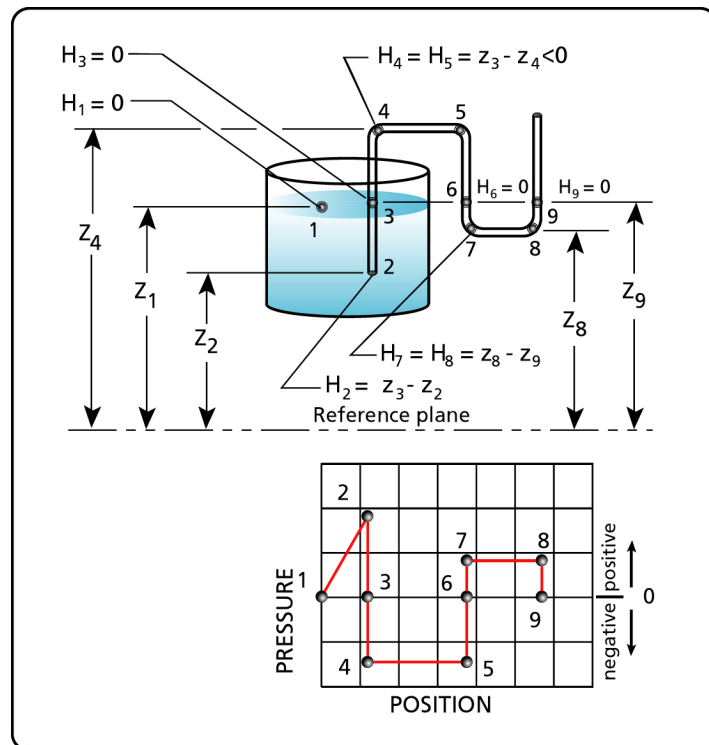


Figure 1-19 The pressure distribution in a static system.

We create relative negative pressure everyday with a straw. Find some flexible tubing and try the experiment shown on Figure 1-20 and Figure 1-24.

Try the following simple experiment. Get a small container and a short length of clear plastic tube. Our goal will be to put some water on a shelf so to speak.

1. Suction is applied to the tube and the liquid is lifted up to point 4.
2. Bend the tube as you apply suction to get the fluid past point 5. At this point a siphon (see section 1.8) is established.
3. The tube is bent at points 7 and 8 and the liquid level establishes itself at point 9, which is the same level as point 1.

The liquid in the tube remains stable and suspended at the level of point 4 and 5. Liquid has been raised from a lower elevation at point 1 to a higher one at point 4, like putting a book on a shelf. If the tube was punctured at point 4 or 5, what would happen? Air would enter the tube and the liquid would drop to its lowest level.

We have managed to create negative relative pressure at point 4, which is easily maintained without further intervention.

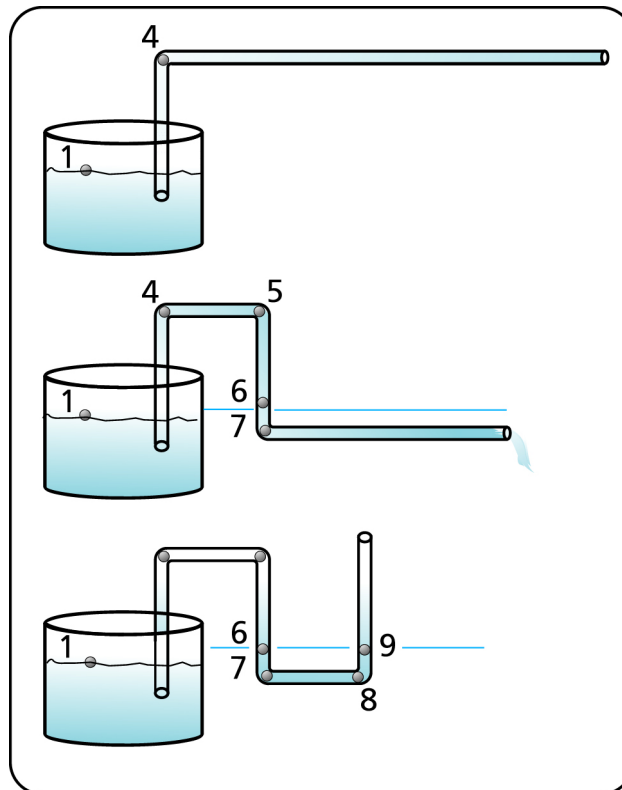


Figure 1-20 Creating negative pressure.

Use a longer tube this time, fill it with water and put your finger on the end of the tube sealing it off. The lower end of the tube is open (see Figure 1-21a). It is possible to suspend a column of water 34 feet high by sealing the top. This creates a volume of zero pressure at the top end, between the finger and the fluid surface. At the bottom end, which is open, atmospheric pressure is pushing on the fluid in an upward direction. The weight of the liquid column is balanced by the force generated by atmospheric pressure.

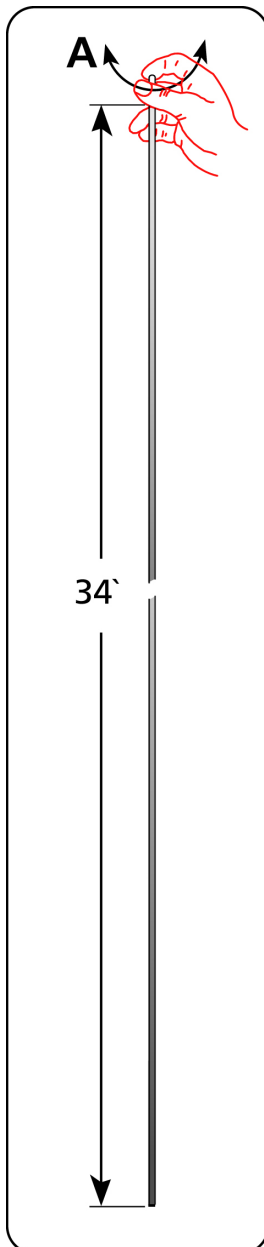


Figure 1-21a Water suspended from an open tube 34 feet high.

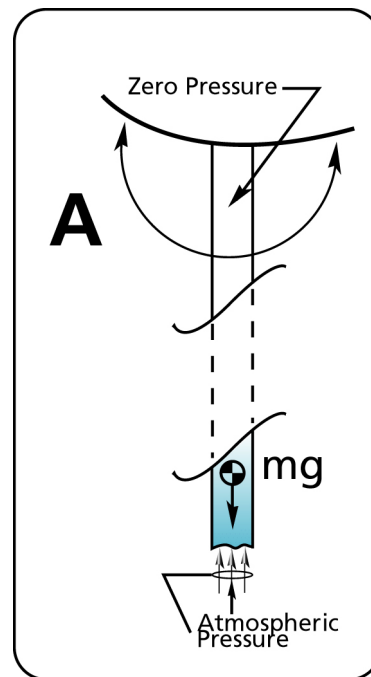


Figure 1-21b Difference in pressure in a water column suspended from an open tube 34 feet high.

A common unit in North America for measuring pressure is the psig (or pound per square inch gauge). Zero psig corresponds to the level of pressure in the local atmosphere. The “g” stands for gauge, meaning dial gauge. The equivalent to 0 psig in pressure head is 0 feet of fluid. These units are relative to the local atmospheric pressure or atmospheric pressure head. Pressure in certain parts of the system can drop below the local atmospheric pressure, and become negative. An area of negative pressure is under a vacuum. A breach of the containment wall, in an area under vacuum, will cause air to be drawn into the system. This is what would happen if the tube were punctured at point 4 in Figure 1-20. The units often used to express low pressure are *psia* (pounds per square inch absolute). The levels of pressure head are expressed in *feet of fluid absolute* or *in Hg* (inch of Mercury). These units are absolute, and are therefore not relative to any other pressure. A perfect vacuum corresponds to 0 psia. Figure 1-22 shows graphically the relationship between absolute and relative pressure. The atmospheric pressure at sea level is 14.7 psia. Not all plants are at sea level, for example, Johannesburg is 5,200 feet above sea level and the local atmospheric pressure is 12 psia. This effect has to be considered when calculating the available N.P.S.H. (Net Positive Suction Head) at the pump suction (see Chapter 3).

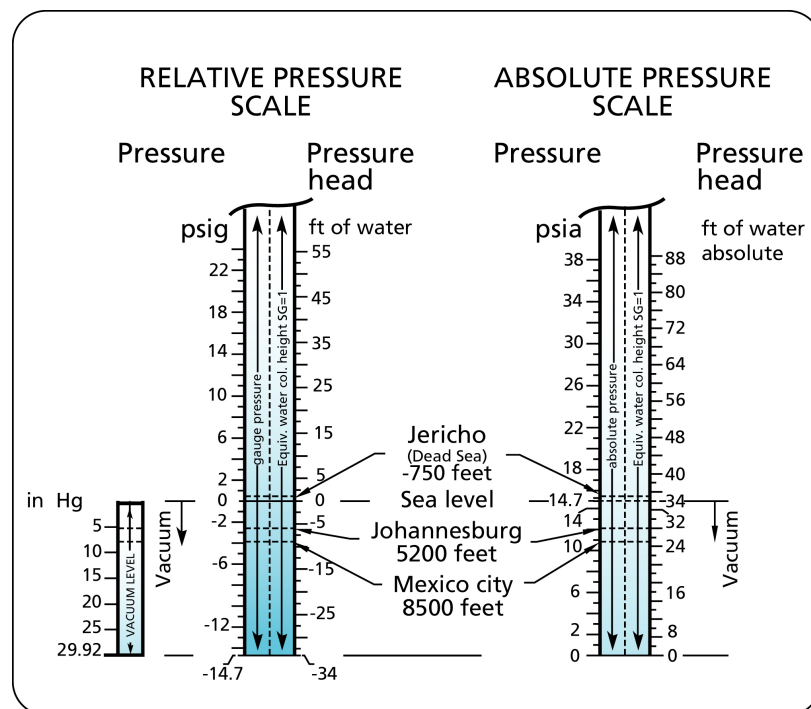


Figure 1-22 Absolute vs. relative pressure scales.

The relationship between an absolute (psia) and a relative (psig) pressure measurement is:

$$p(\text{psia}) = p(\text{psig}) + p_A(\text{psia}) \quad [1-4]$$

where p_A is the local barometric or atmospheric pressure in psia (i.e. $p_A = 14.7$ psia at sea level).

1.8 THE SIPHON EFFECT

At first glance, a fluid moving vertically upwards without assistance creates a surprising effect. Figure 1-23 compares the movement of a rope with that of a ball. Both objects are solid, however the rope can emulate the behavior of a fluid where a ball cannot. A ball moves toward an incline and encounters a rise before it gets to a sharp drop; can it get over the hump without any intervention? No, not if it has a low velocity. Imagine the ball stretched into the shape of a rope, lying on a smooth surface, and draped across the hump. Even when starting from rest, the rope will slide down and drag the overhung part along with it. A fluid in a tube will behave in the same way as the rope.

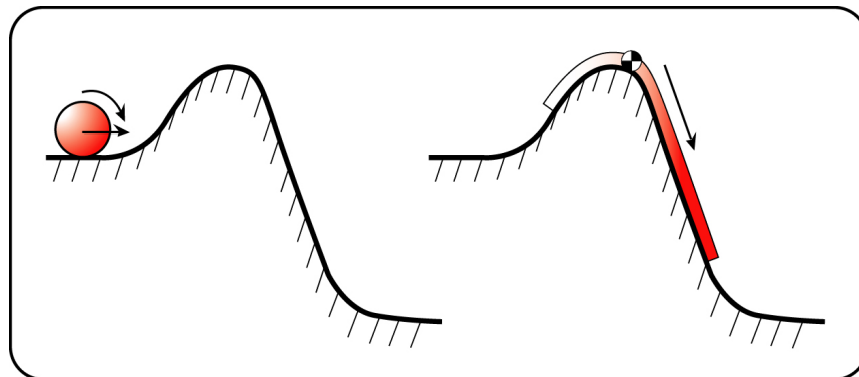


Figure 1-23 A siphon as a rope.

A volume of fluid is formless. A fluid will take on the shape of its container, whatever shape it may be. Its natural tendency is to lie flat. Gravity (or potential energy) is responsible for this behavior. Gravity is also responsible for the siphon effect.

Figure 1-24 shows an experiment that requires a few feet of flexible tube. Fill the tube with water and keep the bottom end sealed in some manner. Pinch the end of the tube at point 1, turn it around 180° to form a U shape as in position C.

Release the end of the tube at point 1. What happens? No fluid leaves the tube. Why? If the water were to come out on the short side then a void would be created in the tube on the level of point 2. A void would produce a volume under low pressure. Low relative pressure acts as a pulling force on the short fluid column. Actually, it is not low pressure that pulls the fluid up but atmospheric pressure that pushes the short column of fluid upward. Therefore, fluid coming out at point 1 would create a vacuum at point 2 and a vacuum stops the movement so that there can be no movement out at point 1. What this means is that the pressure at point 1 (atmospheric pressure) is sufficient to prevent the short column of fluid from moving downward. Why, because if it did not, a void would have to be created at point 2.

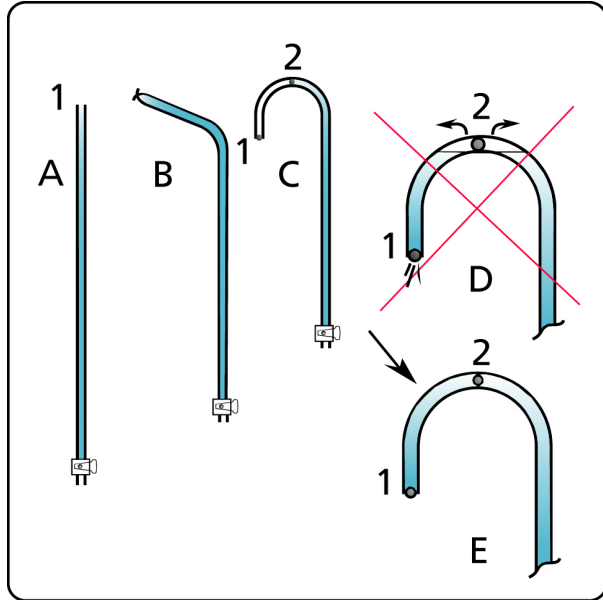


Figure 1-24 Water suspended in an open tube.

The effect of creating a void at point 2 would reduce the pressure to 0 psia. This low pressure can suspend a column of water 34 feet high. This is clearly not necessary for the short column of fluid to the left of 2. Something less than a void needs to be created to suspend the short column of fluid. In Figure 1-24 E, a reduced pressure is present at point 2 which suspends the short column. There is no void required to suspend the short column.

The following experiment will show how easy it is to create low pressure. The effect produced is surprising and shows up an unusual property of fluids, the ability of fluids to be suspended in mid air without apparent means of support.

Experiment No.1

The experiment consists of a vertical tube, full of water, and closed at the bottom end. We take the top end and turn it around vertically downward as shown in Figure 1-25. What happens to the fluid in the tube? Is it in equilibrium, is it suspended, or will some portion of it drop out of the tube?

If the fluid is suspended, there must be a balance of forces that holds it in place, preventing it from falling out of the short end of the tube.

The pressure p_0 within the fluid produces a force F_0 at the section of point 0 (see Figure 1-25). Similarly, the atmospheric pressure p_A produces a force F_A at the end of the tube. W is the weight of that portion of fluid between point 0 and A.

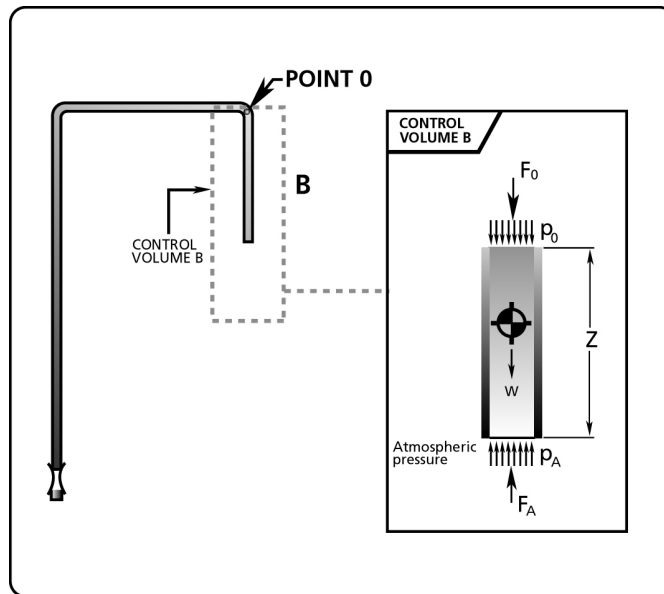


Figure 1-25 Balance of forces between points 0 and A.

The balance of forces is:

$$F_A = F_0 + W \quad \text{also} \quad F = p \times A \quad \text{then} \quad p_A \times A = p_0 \times A + \gamma z A$$

Therefore

$$p_A = p_0 + \gamma z$$

For the fluid to be in equilibrium, p_0 must be smaller than p_A . This means that p_0 will be negative with respect to the atmospheric pressure.

There are two principles in the following argument that should be made clear:

- *In a static system, the fluid particles on the same level are at the same pressure.*
- *Fluids are incompressible.*

We know that for the fluid to be stable there must be a balance of forces. How does this balance of forces come about? Let's see if we can duplicate this experiment without bending any tubes.

Experiment No.2

Let's start with a vertical tube full of water with one end closed as shown in Figure 1-26. If we apply a source of vacuum, the fluid will remain exactly where it is since it is incompressible. In other words, if the pressure is lowered the fluid does not expand and alternatively, if the pressure is raised it does not contract.

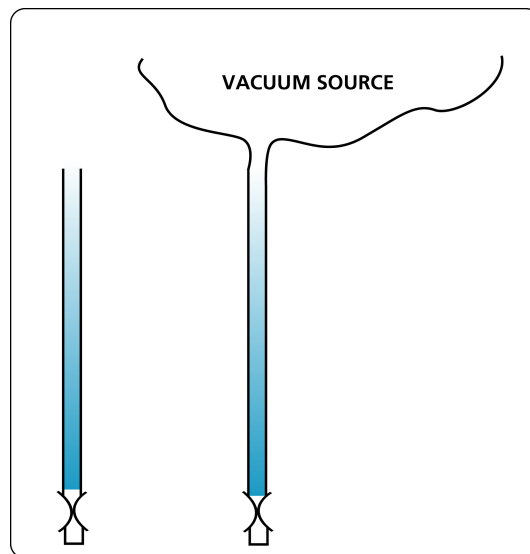


Figure 1-26 The level in the tube does not change when we apply a vacuum.

Attach a tee to the top end of the tube, then a short leg to the tee and connect one branch to a reservoir. Reattach the vacuum source to the tee as in Figure 1-27. The fluid is pulled up the short leg causing it to be in balance and therefore suspended. If we shut off the vacuum source and remove the reservoir, we have exactly the exact same system we started out with in Figure 1-25.

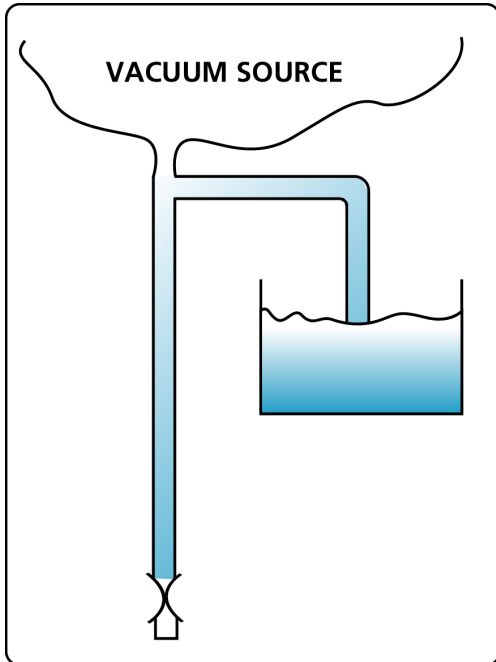


Figure 1-27 Lifting fluid with a source of vacuum.

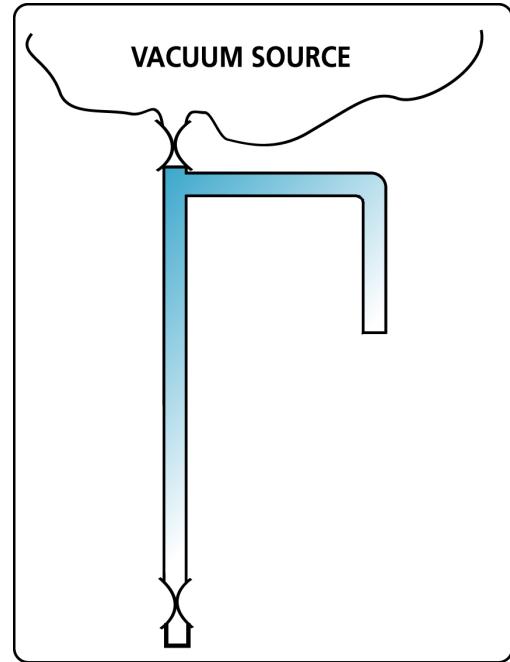


Figure 1-28 The vacuum source is disconnected and the fluid is suspended.

We managed to create a similar system to the original one (Figure 1-25) without bending the tube. We know that the pressure in the tube drops as we raise a fluid vertically from the outlet. It drops just sufficiently to suspend the column of fluid. This was made apparent as we applied a vacuum to lift the fluid. The bending of the tube in Figure 1-25 disguises this effect, giving us a suspended column of fluid without a clear indication of the mechanism. Experiment no. 2 shows the mechanism by which the fluid is suspended.

A typical siphon situation is shown in Figure 1-29. The graph shows how the pressure head varies within the system. In the next chapter, we will develop the method required to calculate the pressure head at any location in the system.

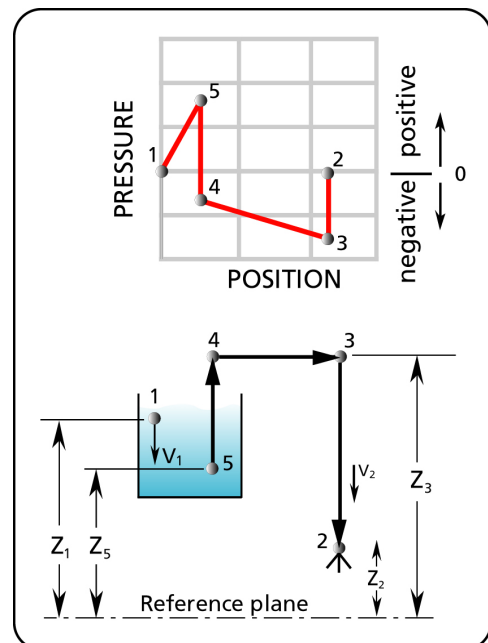


Figure 1-29 The pressure variation within a simple siphon system.

1.9 SPECIFIC GRAVITY

We often need to calculate the pressure head that corresponds to the pressure. Pressure can be converted to pressure head or fluid column height for any fluid. However, not all fluids have the same density. Water for example has a density of 62.34 pounds per cubic foot whereas gasoline has a density of 46.75 pounds per cubic foot. Specific gravity is the ratio of the fluid density to water density at standard conditions. By definition water has a specific gravity (SG) of 1. To convert pressure to pressure head, the specific gravity SG of the fluid must be known. The specific gravity of a fluid is:

$$S G = \frac{\rho_F}{\rho_W}$$

where ρ_F is the fluid density and ρ_W is water density at standard conditions. Since

$$p = \gamma_F z = \frac{\rho_F g z}{g_c} \quad \text{and} \quad \rho_F = SG \rho_W \quad \text{therefore} \quad p = SG \frac{\rho_W g z}{g_c}$$

where γ_F is the fluid density in terms of weight per unit volume and ρ_F is the density in terms of mass per unit volume. The constant g_c is required to provide a relationship between mass in lbm and force in lbf (see Appendix D).

The quantity $\rho_W g/g_c$ ($\rho_W = 62.34 \text{ lbm/ft}^3$ for water at 60 °F) is:

$$\frac{\rho_W g}{g_c} = \frac{62.34(\text{lbm/ft}^3) \times 32.17(\text{ft/s}^2)}{32.17(\text{lbm-ft/lbf-s}^2)} \times \frac{1(\text{ft})}{144(\text{in}^2)} = \frac{1}{2.31} \left(\frac{\text{lbf}}{\text{in}^2\text{-ft}} \right)$$

After simplification, the relationship between the fluid column height and the pressure at the bottom of the column is:

$$p(\text{psi}) = \frac{1}{2.31} SG z(\text{ft of fluid})$$

[1-5]

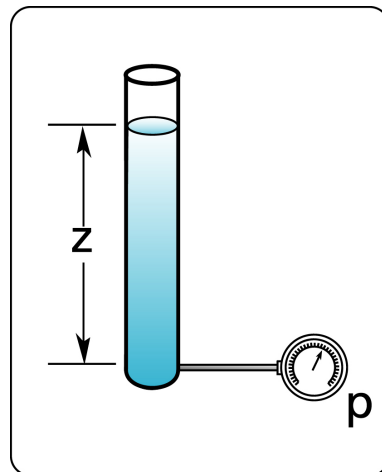


Figure 1-30 Pressure vs. elevation in a fluid column.

Here he goes again with the siphon.

OK, maybe not everyone has the same interest in siphons as I do. The explanation for the behavior of a siphon is quite simple: a siphon is like a rope: if you pull on one end the other will follow. Why is it important to know how a siphon works? Siphons by their very nature produce an area of low pressure. A feed pipe with top entry to a tank behaves like a siphon. Any area in a piping system that is higher than the discharge point will likely be under low pressure.